

We claim:

1. A composition comprising an aromatic binder system and a metal powder, wherein said aromatic binder system and said metal powder are mixed to form a feedstock for powder metallurgy forming techniques.
2. The composition as recited in Claim 1, wherein said powder metallurgy forming techniques are selected from the group consisting of injection molding, extrusion, compression molding, powder rolling, blow molding, laser forming, isostatic pressing, spray forming, and combinations thereof.
3. The composition as recited in Claim 1, wherein said aromatic binder system comprises at least one aromatic species.
4. The composition as recited in Claim 3, wherein said aromatic species comprises a polycyclic aromatic.
5. The composition as recited in Claim 4, wherein said polycyclic aromatic is selected from the group consisting of naphthalene, anthracene, pyrene, , phenanthrenequinone, and combinations thereof.
6. The composition as recited in Claim 1, wherein said aromatic binder system comprises benzene and naphthalene.
7. The composition as recited in Claim 3, wherein said aromatic species comprises less than approximately 40% by volume of said feedstock.
8. The composition as recited in Claim 3, wherein said aromatic species comprises approximately 29% to 37% by volume of said feedstock.

9. The composition as recited in Claim 1, wherein said metal powder is selected from the group consisting of refractory metals, getter materials, alkaline earth metals, group IV metals, and combinations thereof.
10. The composition as recited in Claim 9, wherein said getter materials are selected from the group consisting of Al, Mg, Th, U, Ba, Ta, Nb, P, and combinations thereof.
11. The composition as recited in Claim 9, wherein said refractory metals are selected from the group consisting of Mo, W, Ta, Rh, Nb, and combinations thereof.
12. The composition as recited in Claim 1, wherein said metal powder is selected from the group consisting of Ti, Zr, Hf, and combinations thereof.
13. The composition as recited in Claim 1, wherein said metal powder comprises a metal alloy.
14. The composition as recited in Claim 13, wherein said metal alloy comprises at least one metal selected from the group consisting of refractory metals, getter materials, alkaline earth metals, group IV metals, and combinations thereof.
15. The composition as recited in Claim 14, wherein said metal alloy comprises Ti-6Al,4V.
16. The composition as recited in Claim 1, wherein said metal powder comprises a metal compound.
17. The composition as recited in Claim 16, wherein said metal compound comprises at least one metal selected from the group consisting of refractory metals, getter materials, alkaline earth metals, group IV metals, and combinations thereof.

18. The composition as recited in Claim 16, wherein said metal compound comprises a metal hydride.
19. The composition as recited in Claim 18, wherein said metal hydride comprises  $\text{TiH}_2$ .
20. The composition as recited in 16, wherein said metal compound comprises an intermetallic compound.
21. The composition as recited in 20, wherein said intermetallic compound comprises  $\text{TiAl}_x$ .
22. The composition as recited in Claim 1, wherein said metal powder is selected from the group comprising elemental metals, metal alloys, metal compounds, and combinations thereof.
23. The composition as recited in Claim 1, wherein said metal powder is selected from the group consisting of Ti,  $\text{TiH}_2$ , Ti-6Al,4V, and combinations thereof.
24. The composition as recited in Claim 1, wherein said metal powder comprises at least approximately 45% by volume of said feedstock.
25. The composition as recited in Claim 1, wherein said metal powder comprises approximately 45% to 95% by volume of said feedstock.
26. The composition as recited in Claim 1, wherein said metal powder comprises approximately 54.6% to 70% by volume of said feedstock.
27. The composition as recited in Claim 1, wherein said aromatic binder system further comprises a polymer.
28. The composition as recited in Claim 27, wherein said polymer comprises up to approximately 10% by volume of the feedstock.

29. The composition as recited in Claim 27, wherein said polymer comprises a thermoplastic polymer.
30. The composition as recited in Claim 29, wherein said thermoplastic polymer is selected from the group consisting of ethylene vinyl acetate, polyethylene, butadiene-based polymers, and combinations thereof.
31. The composition as recited in Claim 27, wherein said polymer comprises a thermoset polymer.
32. The composition as recited in Claim 31, wherein said thermoset polymer is selected from the group consisting of polymethylmethacrylates, epoxies, unsaturated polyesters, and combinations thereof.
33. The composition as recited in Claim 27, wherein said polymer comprises a polymer mixture of at least one thermoplastic polymer and at least one thermoset polymer.
34. The composition as recited in Claim 33, wherein said thermoplastic polymer comprises approximately 2.1% to 5.1% by volume of said feedstock.
35. The composition as recited in Claim 33, wherein said thermoset polymer comprises approximately 2.3% by volume of said feedstock.
36. The composition as recited in Claim 33, wherein said polymer mixture comprises up to approximately 10% by volume of said feedstock.
37. The composition as recited in Claim 33, wherein said polymer mixture comprises approximately 4.4% by volume of said feedstock.
38. The composition as recited in Claim 1, wherein said aromatic binder system further comprises a surfactant.

39. The composition as recited in Claim 38, wherein said surfactant comprises a nonionic surfactant.
40. The composition as recited in Claim 38, wherein said surfactant comprises Surfonic N-100<sup>®</sup>.
41. The composition as recited in Claim 38, wherein said surfactant comprises up to approximately 3% of the volume of said feedstock.
42. The composition as recited in Claim 38, wherein said surfactant comprises approximately 2.3% of the volume of said feedstock.
43. The composition as recited in Claim 1, wherein said aromatic binder system further comprises a lubricant.
44. The composition as recited in Claim 43, wherein said lubricant is selected from the group consisting of organic fatty acids, metallic salts, solid waxes and combinations thereof.
45. The composition as recited in Claim 44, wherein said organic fatty acid is selected from the group comprising stearic acid, branched versions of stearic acid, substituted versions of stearic acid, and combinations thereof.
46. The composition as recited in Claim 44, wherein said metallic salts are selected from the group consisting of sodium stearate, calcium stearate, and combinations thereof.
47. The composition as recited in Claim 44, wherein said solid waxes are selected from the group consisting of microcrystalline waxes, paraffin waxes, caruba wax, and combinations thereof.

48. The composition as recited in Claim 43, wherein said lubricant comprises up to approximately 3% of the volume of said feedstock.
49. The composition as recited in Claim 43, wherein said lubricant comprises approximately 1.5% of the volume of said feedstock.
50. The composition as recited in Claim 1, further comprising at least one additional metal powder.
51. The composition as recited in Claim 50, wherein said additional metal powder comprises a sintering aid.
52. The composition as recited in Claim 51, wherein said sintering aid comprises silver.
53. The composition as recited in Claim 50, wherein said additional metal powder comprises an alloying powder.
54. A method of forming metal articles comprising the steps of:
  - a. providing a metal powder;
  - b. providing an aromatic binder system;
  - c. mixing said metal powder and said aromatic binder system, thereby producing a feedstock; and
  - d. processing said feedstock into a metal article using a powder metallurgy forming technique.
55. The method as recited in Claim 54, wherein said metal powder is selected from the group consisting of refractory metals, getter materials, alkaline earth materials, group IV metals, and combinations thereof.

56. The method as recited in Claim 54, wherein said metal powder comprises a metal alloy.
57. The method as recited in Claim 56, wherein said metal alloy comprises at least one metal selected from the group consisting of refractory metals, getter materials, alkaline earth metals, group IV metals, and combinations thereof.
58. The method as recited in Claim 57, wherein said metal alloy comprises Ti-6Al,4V.
59. The method as recited in Claim 54, wherein said metal powder comprises a metal compound.
60. The method as recited in Claim 59, wherein said metal compound comprises at least one metal selected from the group consisting of refractory metals, getter materials, alkaline earth metals, group IV metals, and combinations thereof.
61. The method as recited in Claim 59, wherein said metal compound comprises a metal hydride.
62. The method as recited in Claim 61, wherein said metal hydride comprises  $\text{TiH}_2$ .
63. The method as recited in Claim 54, wherein said metal powder is selected from the group comprising elemental metals, metal alloys, metal compounds, intermetallic compounds, and combinations thereof.
64. The method as recited in Claim 54, wherein said metal powder is selected from the group consisting of Ti,  $\text{TiH}_2$ , Ti-6Al,4V, and combinations thereof.
65. The method as recited in Claim 54, wherein said metal powder comprises at least approximately 45% of the volume of said feedstock.

66. The method as recited in Claim 54, wherein said metal powder comprises approximately 54.6% to 70% of the volume of said feedstock.
67. The method as recited in Claim 54, wherein said aromatic binder system comprises at least one aromatic species.
68. The method as recited in Claim 67, wherein said aromatic species comprises a polycyclic aromatic.
69. The method as recited in Claim 68, wherein said polycyclic aromatic is selected from the group consisting of naphthalene, anthracene, pyrene, phenanthrenequinone, and combinations thereof.
70. The method as recited in Claim 54, wherein said aromatic binder system comprises naphthalene and benzene.
71. The method as recited in Claim 67, wherein said aromatic species comprises less than approximately 40% of the volume of said feedstock.
72. The method as recited in Claim 67, wherein said aromatic species comprises approximately 29% to 37% of the volume of said feedstock.
73. The method as recited in Claim 54, wherein said aromatic binder system further comprises a polymer.
74. The method as recited in Claim 73, wherein said polymer comprises up to approximately 10% of the volume of said feedstock.
75. The method as recited in Claim 73, wherein said polymer comprises a thermoplastic polymer.



76. The method as recited in Claim 75, wherein said thermoplastic polymer is selected from the group consisting of ethylene vinyl acetate, polyethylene, butadiene-based polymers, and combinations thereof.
77. The method as recited in Claim 73, wherein said polymer comprises a thermoset polymer.
78. The method as recited in Claim 77, wherein said thermoset polymer is selected from the group consisting of polymethylmethacrylates, epoxies, unsaturated polyesters, and combinations thereof.
79. The method as recited in Claim 73, wherein said polymer comprises a polymer mixture of at least one thermoplastic polymer and at least one thermoset polymer.
80. The method as recited in Claim 79, wherein said thermoplastic polymer comprises approximately 2.1% to 5.1% of the volume of said feedstock.
81. The method as recited in Claim 79, wherein said thermoset polymer comprises approximately 2.3% of the volume of said feedstock.
82. The method as recited in Claim 79, wherein said polymer mixture comprises up to approximately 10% of the volume of said feedstock.
83. The method as recited in Claim 79, wherein said polymer mixture comprises up to approximately 4.4% of the volume of said feedstock.
84. The method as recited in Claim 54, wherein said aromatic binder system further comprises a surfactant.
85. The method as recited in Claim 84, wherein said surfactant comprises a nonionic surfactant.

86. The method as recited in Claim 84, wherein said surfactant comprises Surfonic N-100<sup>®</sup>.
87. The method as recited in Claim 84, wherein said surfactant comprises up to approximately 3% of the volume of said feedstock.
88. The method as recited in Claim 84, wherein said surfactant comprises up to approximately 2.3% of the volume of said feedstock.
89. The method as recited in Claim 54, wherein said aromatic binder system further comprises a lubricant.
90. The method as recited in Claim 89, wherein said lubricant is selected from the group consisting of organic fatty acids, metallic salts, solid waxes and combinations thereof..
91. The method as recited in Claim 89, wherein said lubricant comprises stearic acid.
92. The method as recited in Claim 89, wherein said lubricant comprises up to approximately 3% of the volume of said feedstock.
93. The method as recited in Claim 89, wherein said lubricant comprises 1.5% by volume of said feedstock.
94. The method as recited in Claim 54, further comprising the steps of providing at least one alloying powder and mixing said alloying powder with said metal powder and said aromatic binder system.
95. The method as recited in Claim 94, wherein said alloying powder comprises a sintering aid.
96. The method as recited in Claim 95, wherein said sintering aid comprises silver.

97. The method as recited in Claim 54, wherein said mixing comprises using a high-shear mixer.
98. The method as recited in Claim 97, wherein said feedstock comprises naphthalene and a Ti-based metal powder, and said high-shear mixer operates at 50 RPM.
99. The method as recited in Claim 54, wherein said step c occurs at a temperature greater than a melting point of said aromatic binder system.
100. The method as recited in Claim 99, wherein said feedstock comprises naphthalene and a Ti-based powder, and said temperature comprises approximately 85 °C.
101. The method as recited in Claim 54, wherein said step c further comprises the steps of solidifying and pelletizing said feedstock.
102. The method as recited in Claim 101, wherein said solidifying comprises cooling said feedstock to a temperature less than a freezing point of said aromatic binder system.
103. The method as recited in Claim 102, wherein said feedstock comprises naphthalene and a Ti-based powder, and said temperature comprises approximately 78 °C.
104. The method as recited in Claim 101, wherein said pelletizing comprises using a pelletizer to form pellets from a rod of feedstock.
105. The method as recited in Claim 101, wherein said pelletizing comprises using said high-shear mixer to form pellets from said feedstock.
106. The method as recited in Claim 54, wherein said powder metallurgy forming technique is selected from the group consisting of injection molding, extrusion,

compression molding, powder rolling, blow molding, isostatic pressing, and combinations thereof.

107. The method as recited in Claim 54, wherein said processing further comprises the steps of:
- a. injecting said feedstock into a mold, thereby forming a green state;
  - b. debinding said green state, thereby forming a brown state;
  - c. sintering said brown state; and
  - d. cooling, thereby forming a metal article having an increase in C and O content each less than or equal to approximately 0.2 wt%, relative to said metal powder.
108. The method as recited in Claim 107, wherein said metal article further comprises an increase in N content less than or equal to 0.2 wt%, relative to said metal powder.
109. The method as recited in Claim 107, wherein said injecting comprises maintaining said feedstock at a temperature above a melting temperature of said aromatic binder system.
110. The method as recited in Claim 109, wherein said feedstock comprises naphthalene and a Ti-based powder and said temperature is approximately 85 °C.
111. The method as recited in Claim 110, wherein said feedstock is injected through a barrel held at a temperature of approximately 120 °C to 140 °C.
112. The method as recited in Claim 107, wherein said mold is maintained at a temperature below a freezing point of said aromatic binder system.

113. The method as recited in Claim 112, wherein said feedstock comprises naphthalene and a Ti-based powder and said temperature is less than approximately 85 °C.
114. The method as recited in Claim 107, wherein said feedstock comprises naphthalene and a Ti-based powder and said temperature is approximately 78 °C.
115. The method as recited in Claim 107, wherein said injecting occurs at an injection pressure from approximately 3,000 to 20,000 psi.
116. The method as recited in Claim 107, wherein said debinding comprises heating said green state in a first vacuum to a temperature less than a melting point of said aromatic binder system.
117. The method as recited in Claim 116, wherein said first vacuum is a pressure below approximately 760 Torr.
118. The method as recited in Claim 116, wherein said first vacuum is a pressure of approximately 35 Torr.
119. The method as recited in Claim 107, wherein said debinding lasts approximately 8 to 48 hours.
120. The method as recited in Claim 107, wherein said debinding comprises a drying technique utilizing a densified fluid.
121. The method as recited in Claim 120, wherein said densified fluid comprises propane.
122. The method as recited in Claim 107, wherein said sintering comprises sintering said brown state in a hydrogen gas atmosphere.

123. The method as recited in Claim 107, wherein said sintering comprises sintering said brown state under a second vacuum.
124. The method as recited in Claim 123, wherein said second vacuum is a pressure below approximately 760 Torr.
125. The method as recited in Claim 123, wherein said second vacuum is a pressure below approximately  $1 \times 10^{-5}$  Torr.
126. The method as recited in Claim 107, wherein said sintering comprises sintering said brown state under ambient conditions selected from the group consisting of a vacuum, a hydrogen cover gas, and combinations thereof.
127. The method as recited in Claim 107, wherein said sintering further comprises the steps of:
- a. ramping a temperature to a first set point at a first ramp rate;
  - b. holding said first set point for a first period of time;
  - c. ramping said temperature to a second set point at a second ramp rate;
  - d. holding said second set point for a second period of time; and
  - e. cooling.
128. The method as recited in Claim 127, wherein said first set point is within the temperature range of approximately 300 °C to 600 °C.
129. The method as recited in Claim 127, wherein said first ramp rate is within the temperature range of approximately 1 to 20 °C per minute.
130. The method as recited in Claim 127, wherein said first period of time is approximately 60 to 180 minutes.

131. The method as recited in Claim 127, wherein said first period of time is approximately 90 minutes.
132. The method as recited in Claim 127, wherein said second set point is within the temperature range of approximately 1000 °C to 1350 °C.
133. The method as recited in Claim 127, wherein said second set point is approximately 1100 °C.
134. The method as recited in Claim 127, wherein said second ramp rate is within the temperature range of approximately 1 to 20 °C per minute.
135. The method as recited in Claim 127, wherein said first period of time is within approximately 1 to 6 hours.
136. The method as recited in Claim 127, wherein said first period of time is approximately 4 hours.
137. The method as recited in Claim 127, wherein said cooling comprises using a furnace chiller.
138. A metal-injection-molded metal article processed in accordance with the method of Claim 54, said metal-injection-molded article having an increase in C and O contents each less than or equal to 0.2 wt% relative to a metal powder from which said article is processed.
139. The metal-injection-molded metal article as recited in Claim 138 further comprising an increase in N content less than or equal to 0.2 wt% relative to said metal powder.
140. The metal-injection-molded metal article as recited in Claim 138, wherein said metal article comprises Ti.

141. The metal-injection-molded metal article as recited in Claim 138, wherein said metal article comprises a metal alloy.
142. The metal-injection-molded metal article as recited in Claim 141, wherein said metal alloy comprises a Ti alloy.
143. The metal-injection-molded metal article as recited in Claim 138, wherein said metal article comprises a biomedical prosthetic device.
144. An improved metal-injection-molded article, wherein said article is processed from a metal powder having a C and O content, the improvement comprising an increase in said C and O contents each less than or equal to 0.2 wt%.
145. The metal-injection-molded article as recited in Claim 144, wherein said article is processed from a metal powder further having a N content, the improvement comprising an increase in said C, O, and N contents each less than or equal to 0.2 wt%
146. The metal-injection-molded article as recited in Claim 144, wherein said article comprises Ti.
147. The metal-injection-molded article as recited in Claim 146, wherein said Ti comprises a Ti alloy.